AD-A047 250 NATIONAL AVIATION FACILITIES EXPERIMENTAL CENTER ATL--ETC F/G 9/1
REBUILDING CATHODE RAY TUBES.(U)
OCT 77 J W ASCHENBACH

UNCLASSIFIED FAA-NA-77-14 FAA-RD-77-61 NL

| OF |

ADA047 250

END

DATE FILMED

1 - 78

DDC

Report No.FAA-RD-77-[redacted] 61

13

mc

REBUILDING CATHODE RAY TUBES

John W. Aschenbach

October 1977

FINAL REPORT

Document is available to the public through the
National Technical Information Service
Springfield, Virginia 22151

Prepared for

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Systems Research & Development Service
Washington, D.C. 20590

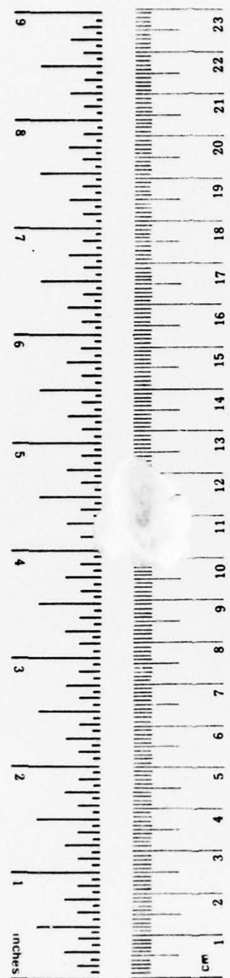
NOTICE

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

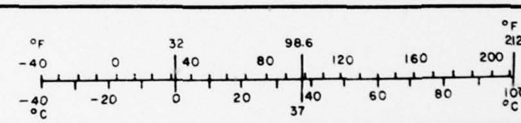
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



Technical Report Documentation Page

1. Report No. 18 19 FAA-RD-77-[redacted] 61	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle 6 REBUILDING CATHODE RAY TUBES.	11	5. Report Date Oct[redacted] [redacted]77 12 26p. 6. Performing Organization Code
7. Author(s) 10 John W. Aschenbach	14	8. Performing Organization Report No. FAA-NA-77-14
9. Performing Organization Name and Address Federal Aviation Administration National Aviation Facilities Experimental Center Atlantic City, New Jersey 08405		10. Work Unit No. (TRAIS) 11. Contract or Grant No. 124-111-830
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration Systems Research and Development Service Washington, D.C. 20590		13. Type of Report and Period Covered 9 Final rept. Jan[redacted] [redacted]75-Dec[redacted] [redacted]76, 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The Federal Aviation Administration (FAA) was engaged in a program to investigate the feasibility of rebuilding large-size cathode ray tubes (CRT's) for emergency requirements. This report is a summary of the results from the evaluation of rebuilt tubes as supplied by several CRT rebuilders. The sample size was not sufficient to conclude that CRT vendors could be qualified to rebuild special CRT's. Perhaps the most useful result of the investigation and testing was the information obtained relative to commercial television CRT improvements to the FAA CRT rebuilding experiments.

17. Key Words Cathode Ray Tubes	18. Distribution Statement Document is available to the public through the National Technical Information Service, Springfield, Virginia 22151

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	26	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

240550 JB

PREFACE

Acknowledgement is given to the following people for their assistance in this project:

Elmer M. Haynack,
Salvador Roditi,
Ron Katz, and
Brian J. Lynch.

TABLE OF CONTENTS

PRECEDING PAGE NOT FILMED BLANK

LIST OF TABLES

INTRODUCTION

PURPOSE.

This report describes the work and results of a technical evaluation by the National Aviation Facilities Experimental Center (NAFEC) of rebuilt 23-inch monochrome cathode ray tubes (CRT's). The purpose of this project was twofold:

1. To determine the feasibility of rebuilding Federal Aviation Administration (FAA) large CRT's.

2. To provide a basis for qualifying potential suppliers to ensure acceptable rebuilt CRT's.

BACKGROUND.

The sole supplier of glass bulbs for the FAA 23-inch CRT's, the type used in the plan view displays (PVD's) at the air route traffic control centers (ARTCC's), has ceased their manufacture. This has been done because these monochrome CRT's are fabricated from the same basic glass material as the bulbs used in making CRT's for commercial monochrome televisions (TV), and the market for the latter has become essentially replaced by the demand for color receivers. Although it now appears that the FAA could have these bulbs produced from commercial color television glass, the termination of supplying monochrome-type bulbs could create a possibility that the FAA would have no source for procuring new 23-inch CRT's to replace old or faulty tubes in the field. A critical shortage, however, might be avoided by rebuilding bulbs from used FAA 23-inch CRT's. But the original manufacturers of FAA 23-inch CRT's refuse to rebuild them, because the sole supplier of the new glass bulbs does not recommend this process due to safety reasons. After careful review of the problem, Systems Research and Development Service (SRDS), requested NAFEC to investigate the feasibility of rebuilding the 23-inch CRT's, and to provide a basis for qualifying potential suppliers of fully acceptable rebuilt tubes.

The investigation, as initially proposed, was to establish guidelines for, and to select prospective FAA monochrome CRT's to be rebuilt. The next step was to develop specifications and/or a work statement and coordinate this effort through prospective CRT rebuilding vendors with proper plant facilities and technical expertise.

After the guidelines were established and prospective vendors selected, contracts were awarded. A close surveillance of progress in the CRT rebuilding process was necessary, due primarily to the vendor's problem in obtaining an equivalent electron gun. In addition, the 23-inch all-glass bulb required removal of a fiberglass safety boot laminated to the CRT funnel. This process was objectionable to all vendors, because it presented a low-yield problem and created a potentially unsafe processing operation at their plants.

It was originally planned to use plant source inspection of the vendor-rebuilt CRT's by FAA inspectors prior to delivery at NAFEC. However, CRT rebuilders are not generally equipped to provide the test environment that special category manufacturers for government and industry must provide under their quality assurance program standards. This problem was averted by providing the CRT rebuilder with a work statement which basically covered the essential electrical parameters and mechanical accessory requirements of the original FAA-E-2573 CRT specifications. In addition, the safety tests and qualification design tests were waived. These waived requirements were performed at NAFEC, where the original CRT specifications were applied during final testing at the CRT Performance Test Facility. The sample size for test specimens of vendors' contracts was varied, due to cost and time. In addition, all prospective vendors felt the original design lacked the improvements obtained from experience with earlier commercial television CRT problems. Basically, all vendors were concerned about low useful life, insufficient gettering (improper gas ratio), implosion protection over the shoulder area (tension strap and mounting provisions), and the use of the fiberglass funnel protection technique.

It was established early in the investigation and consultations that the vendors believed that the process of rebuilding CRT's, except for very special purpose tubes, would not be difficult to perform. In fact, for most applications, their general opinion was that the process of rebuilding these government-type CRT's would be no more difficult than for commercial television CRT's, except for those with special-type electron guns. With this in mind, and considering that NAFEC has a very extensive CRT testing facility, a minimal number of constraints were placed on the potential vendors.

DISCUSSION

GENERAL.

Through discussions and visits with potential CRT rebuilders who were processing commercial-type CRT's, guidelines for CRT rebuilding and practical work statement information were obtained. In addition, manufacturers of industrial as well as government-type CRT's were contacted.

Current FAA-documented CRT specifications for new CRT production were used as the basic requirement. From the pertinent test parameters of these specifications, the rebuilt CRT test data sheet (in appendix A) and a work statement (in appendix B) were developed. The quality assurance provisions were considerably modified because, if they had not been, then all CRT suppliers would first have been required to pass a first article qualification testing by the NAFEC CRT Test Facility. Many of the rebuilders would then not have been able to participate in the project. NAFEC evaluated each rebuilt CRT before each subsequent CRT was authorized or delivered. It was necessary for most vendors to correct several of their CRT's before an acceptable or usable CRT would be installed in an operational console.

All prospective CRT rebuilders were provided used CRT's and copies of FAA specifications. It was necessary to provide deflection yokes to most vendors so that they could obtain the proper electron gun positioning and element spacing.

PROBLEMS AND SOLUTIONS IN PROCESSING THE CRT'S.

A block diagram of the rebuilding process of a CRT is shown in figure 1. The phosphor was not replaced, because the rebuilders who took part in the program lacked the proper facilities. To deposit new phospher, the FAA would have had to contract from the larger CRT-manufacturing houses, where the cost of developmental contracts for rebuilt tubes would have been prohibitive. Although one of the CRT rebuilders also produced electron guns, none could build the 23-inch high-resolution CRT electron gun. This gun is unique because of the requirement for its elements to be carefully spaced to more exacting tolerances than for commercial guns to ensure peak performance. Unlike the TV-type electron gun, this gun must generate very bright, high-resolution images on a relatively large, flat surface. These special electron guns used by the vendors were purchased separately and required many changes (mostly element spacing and aperture size) before the CRT specifications were satisfied. One prospective CRT rebuilder defaulted, because the electron gun problem was too costly to solve.

None of the rebuilders seemed to have difficulty with their vacuum, bakeout, and purging processes. As was mentioned, however, removal of the fiberglass boot (funnel covering) was objectionable to every rebuilder, primarily for safety reasons. The fiberglass boot was discontinued on commercial television CRT's many years ago. This discontinuance had been recommended by Underwriters Laboratories (UL) to CRT manufacturers for the television industry for both safety and economic reasons. From past experience with commercial TV tubes which once used the fiberglass cover, there reportedly had been numerous implosions during plant processing which were attributed to the removal of this covering. This removal process can cause small and sometimes invisible cracks and chips in the surface of the funnel glass. Perhaps it is conceivable that these added stresses to the glass could cause an implosion sometime later. This is even more critical in the 23-inch tube, with its large, flat surface area. An objection was raised concerning the difficulty in removing the old fiberglass boot without using expensive solvent material, an extremely messy task which created noxious odors. The FAA is developing, with the original tube manufacturer, a 23-inch CRT that utilizes the Kimcode® implosion protection system (contract DOT-A76NA-3029). This system makes use of a high-tension band and a cemented rim band. If a crack would occur in the faceplate area, virtually no movement of the rim glass would take place. This is because the tension band rigidly reinforces the rim periphery, and all fragmented rim glass is firmly cemented to and held in place by the rim band. Due to this immobility of the critical rim area, the entire envelope is essentially reinforced, and there is no sudden, extensive movement of glass, which occurs during a violent implosion. If this system is found to be practical for the 23-inch tubes, it will no longer be necessary to use the fiberglass boot. The Kimcode system is described in a report published by Owens-Illinois, Inc., dated March 1966: "History of Implosion Protection Systems in the United States, 1958-1966." The fiberglass boot protective cover substantially increases the cost of new and rebuilt CRT's.

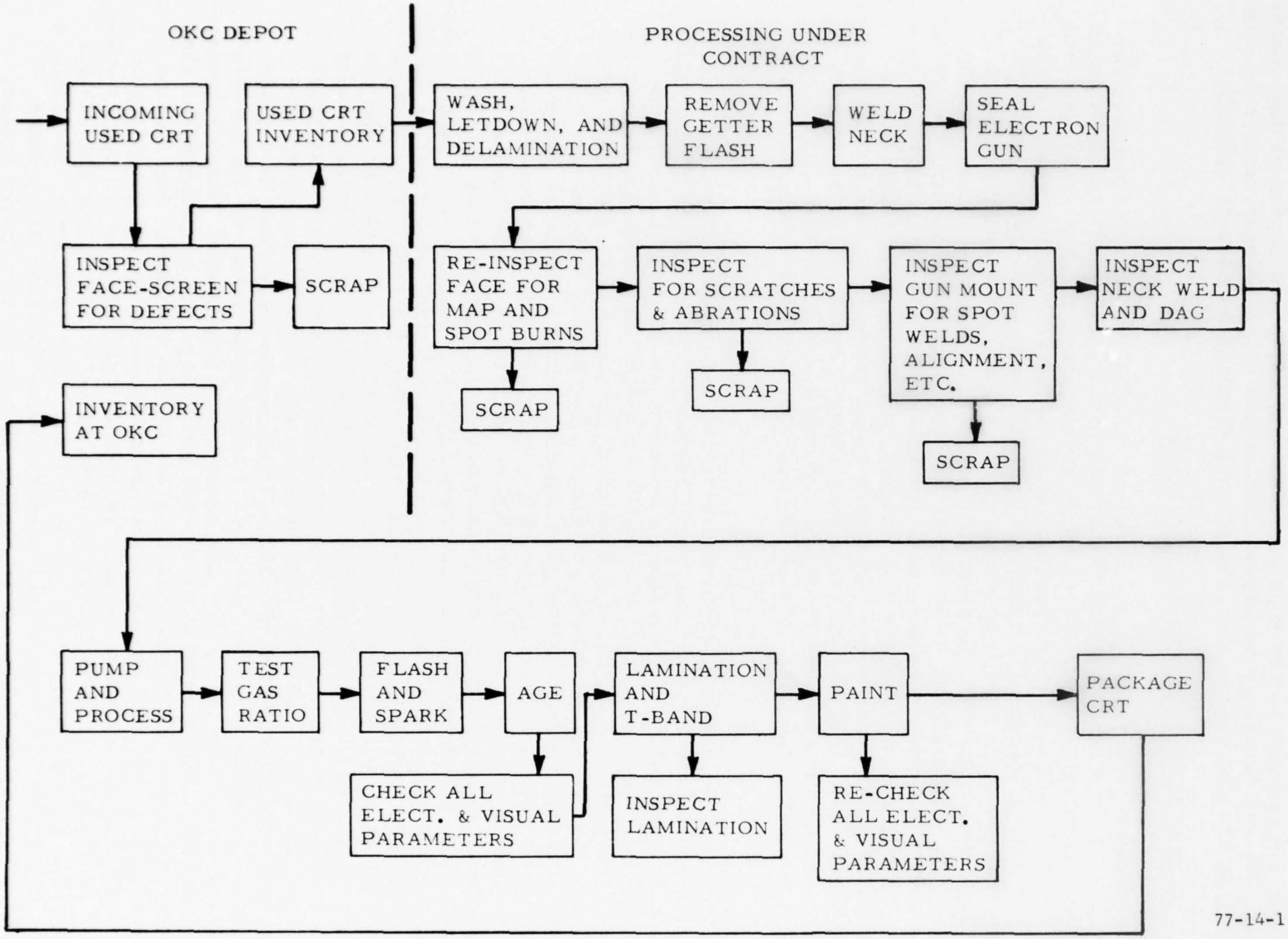


FIGURE 1. CRT REBUILDING PROCESS

During the rebuilding process, the tube is heated to a level near the cold-flow point of the glass. During this step, the relatively flat faceplate (radius of curvature as much as 210 inches) may become too flat causing a reduction in its strength when the tube is re-evacuated. The manufacturer of the glass bulbs used for these tubes has warned the CRT manufacturer that rebuilding these special, large surface area, flat faceplate CRT's could cause fatigue of the glass.

TEST PROCEDURES.

All tests of the rebuilt tubes were perfomed with the CRT Performance Test Set located in the CRT Test Facility at NAFEC. The Performance Test Set is a system composed of a large variety of electro-optical measurement equipment, designed to test a wide range of CRT's. Besides the various power supplies and associated current and voltage meters necessary to bias on the CRT's, the test set is made up of many types of light measurement equipment. They include a photometer, a spectroradiometer, and a microscope with a motorized scanning-micrometer eyepiece whose photometric and positioning output information is digitally fed to a programmable calculator.

All the tubes were tested to see if they met the various specifications necessary to operate in the host display. Resolution measurements were performed at an average line brightness of 50 footlamberts (fL) and a writing rate of 0.3 inches per microsecond. This is the writing rate of normal data on the PVD. "Brite" information on the PVD is written at a rate of 0.15 inches per microsecond, which produces better resolution at the same 50 fL. However, the brightest information used by the controller is usually adjusted to less than 10 fL. Performing the resolution test at the extremely high brightness of 50 fL was, therefore, a more stringent test. The refresh rate used in the evaluation was 60 hertz (Hz) for better accuracy in the data collection. This is because this 60-Hz rate was in synchronization with the frequency of the line power and therefore significantly reduced the oscillations on the data presented on the face of the CRT under test. Fifty-five hertz is the nominal writing rate of the PVD. However, any error introduced by this difference in writing rate is insignificant when weighed against the advantages of making more accurate measurements at 60 Hz. These same resolution tests were run on two new nonrebuilt CRT's from the original manufacturer for comparison. A line-width of no more than 15 mils (1 mil = 0.001 inch) in the screen center and 20 mils at the screen edge, both at a brightness of 50 fL, was considered acceptable.

The tubes were checked for gas ratio, interelectrode leakage currents, stray emission, and center and edge focusing. Gas ratio is a measurement of the amount of gas remaining inside the tube after it has been evacuated. Increasing amounts of residual gas hastens contamination of the cathode and promotes inefficient emission. Therefore, the lower this reading is, the longer the tube life is prolonged. The various leakages are inter-element electric currents present when the tube is properly biased, but without data displayed. Stray light emission is any "noise" visable on the screen other than actual data. An example of this would be the small "ring" that is visible sometimes on an aged tube, which is caused by grid emission. Edge-focusing can be no more than 450 volts above center-screen focusing, which must be in the range of 2,600 volts to 3,000 volts.

The CRT's were checked for their modulation characteristics. Modulation is tested by measuring the amount of control grid drive (voltage above cutoff) necessary to draw 100 microamperes and 300 microamperes of beam current. This test indicates whether or not a tube will be adequately bright when driven by the voltages of the video amplifier used in the host display.

Another step in the testing was the measurement of cutoff voltage. This is a measurement of the control grid threshold voltage, referenced to the cathode, that extinguishes the undeflected spot. This voltage must fall within a specified range in order for a tube to function properly in a given display. Radius of curvature measurements were performed on several of the rebuilt tubes to determine if the faceplate curvature was still within the specification.

The CRT's were also tested to see if they would meet the pressure test delineated in the specification. In this test, the tubes were subjected to 45 pounds per square inch absolute pressure for a period of at least 60 seconds. The pressure was attained within 60 seconds. There was not enough time to finish life testing of the CRT's.

RESULTS.

In the test data of appendix A, the various CRT rebuilders are not directly named, but instead represented by an alphanumeric symbol. The various designators used for individual CRT rebuilders are: D, M, S, W, W/J and V, representing the six companies evaluated. All the CRT's passed the gas ratio, element leakage, and stray light emission specifications. Five tubes had a center-screen focus voltage outside the specified range.

Company D delivered an operationally successful CRT, but elected not to continue any further on the contract, due to the difficulty and cost of obtaining electron guns. They replaced the cathode of the electron gun, and the tube checked out according to most of the original specifications. This tube was installed in a PVD and placed in operational service at NAFEC. Company D, however, did evaluate the expended CRT's delivered by the FAA and concluded that there was entirely too much contamination. This contamination caused the low life of these new CRT's. They believed the electron gun of the original tube also needed improvement.

Company M produced six CRT's, but only two were considered qualified for operational use, and these had poor cathode emission characteristics. These two were installed in display consoles after completion of qualification testing. This CRT rebuilder increased the getter size and changed the grid material (gold plated) for better protection against contamination. These tubes are now being life tested to evaluate the effect of these modifications for improved life.

Company W produced four out of five CRT's considered qualified for life testing. However, only one was of sufficient quality to be used in an operational display. The company added an antenna getter for proposed longer life of the CRT. Placement of the antenna getter was very critical, and the electron gun mounting supports had to be modified. This was necessary because, in operational use,

the CRT is varied from the faceplate being in the vertical plane to the horizontal plane. This transition is not a smooth mechanical function. The antenna getter extends beyond the CRT neck area into the bulb funnel and lies against the funnel sidewall, and any movement will cause it to interfere with the electron beam. These tubes are also being life tested.

Company W/J was engaged in a contract for CRT's which required a direct replacement of the normal Einsel crossover electron gun in the 23-inch diameter CRT with a special parallel-beam electron gun. The contract called for the use of expended CRT's (used) without replacing the phosphor. In this respect, these tubes were rebuilt. The primary intent, however, was to determine if a direct replacement of the crossover electron gun with a parallel-beam type could meet the original electron gun specifications and extend useful life. Only two CRT's were delivered at the time this report was drafted; however, both met the basic electronic and photometric qualifications to function in the display for which it was intended. Life tests and further qualification tests are being conducted, and a separate report on this special CRT will be issued. This tube will also be built as a new CRT; i.e., it will have new phosphor and a new bulb and be compared to a new crossover-gun CRT.

Company V produced one rebuilt CRT for evaluation. This tube was a direct replacement rebuild with no special improvements, and it proved to be equal to the resolution and brightness obtained from new CRT equivalent samples tested. However, during life testing, the tube showed indications of becoming gassy. When the gun socket was disconnected, the glass cap seal opened, and the tube went to air.

Company S produced 7 out of 10 CRT's considered qualified for life testing and possible field operating use. One of these tubes met all the operating specifications. These CRT's were fabricated with the same safety protective techniques used by the television industry and approved by UL. Basically, the mounting accessories normally used by the FAA were replaced with an equivalent "Kimcode®" or "Rimband"® process which affords complete protection around the highest stress points of the CRT (shoulder area). This process requires, for each CRT bulb type, a specific tension pressure of the "T" band which surrounds the CRT shoulder rim band sections with mounting ears. The proper combination was determined by a series of forced implosion testing, because a mathematical model for determining all the safety aspects of glass is, at best, effective only in developing an assumed area of minimum risk. By carefully analyzing each bulb-type for physical properties of the glass and the configuration of the finished CRT, the basic approach to the design is similar to experiments conducted by Kimball Glass Company and Owens-Illinois (the Kimcode method) and as certified by UL.

ANALYSIS.

An example of the actual data sheets used for the tests is included in appendix A (A-1 and A-2). The information from these various tests was combined, where necessary, into a smaller number of categories in the summary data sheets (tables 1 and 2) in this section. These seven groups represent the most important overall characteristics required for a new or rebuilt CRT to operate satisfactorily in its host display.

TABLE 1. REBUILT 23-INCH TUBE SUMMARY DATA SHEET

TUBE IDENTIFICATION	FOCUSING	VOLTAGE BREAKDOWN	AVERAGE RESOLUTION	MODULATION	CUTOFF VOLTAGE	OVERALL DISPLAY LEGIBILITY	MECHANICAL CONSTRUCTION
	Center Screen 2,600 V to 3,000 V	No more than 3 arcs	No more than 15 mils center 20 mils edge	100 μA; 15 V to 35 V 300 μA; 20 V to 50 V	Between -35 V -85 V		
R1*	2,850 V	No arcs	11 mils center 13.5 mils edge	25V 36 V	-46 V	OK	OK
R2*	2,750 V	2 arcs	11.7 mils center 15.0 mils edge	26 V 7 V	-56 V	OK	OK
DI	3,200 V	3 arcs stopped	16 mils center 17 mils edge	20 V 39 V	-47 V	OK	OK
M1	2,500 V	No arcs	17.5 mils center 23 miles edge	16 V Does not make 300 μA	-32 V	OK	Problem with Aquadag
M2	2,500 V	2 arcs	15 mils center 20 mils edge	15 V Does not make 300 μA	-21 V	OK	Problem with Aquadag
W1	2,850 V	No arcs	27 mils center		-49 V	Data looks 'smeared'	OK
W2	2,800 V	No arcs	23 mils center at 20 fL	30 V 50 V	-40 V	OK	OK
W3	2.600 V	No arcs	30 mils center	26 V 44V	-86 V	Characters look 'smeared'	OK
W4	2.800 V	2 arcs	25 mils center	19 V 35 V	-60 V	Bad neck shadow	OK
W5	3,000 V	No arcs	Very poor	11 V 15 V	-40 V	Bad neck shadow	OK

*Not rebuilt. New production CRT's tested for comparative purposes.

TABLE 2. REBUILT 23-INCH TUBE SUMMARY DATA SHEET

TUBE IDENTIFICATION	FOCUSING	VOLTAGE BREAKDOWN	AVERAGE RESOLUTION	MODULATION	CUTOFF VOLTAGE	DISPLAY LEGIBILITY	MECHANICAL CONSTRUCTION
	Center Screen 2,600 V to 3,000 V	No more than 3 arcs	No more than 15 mils center 20 mils edge	100 μA; 15 V to 35 V 300 μA; 20 V to 50 V	Between -35 V to 85 V		
S1		Many arcs			-90 V		OK
S2	2,930 V	2 arcs	19 mils center	27 V 40 V	-67 V	Bad--left side much brighter than right	OK
S3	2,700 V	More than 3 arcs	20 mils center 20 mils edge	22 V 30 V	-42 V	Could not get full deflection	OK
S4	3,500 V	No arcs	25 mils center 25 mils edge	23 V 36 V	-56 V	Neck shadow	OK
S5	2,700 V	2 arcs	19 mils center 18 mils edge	25 V 40 V	-53 V	Neck shadow	OK
S6	2,600	1 arc	14 mils center 20 mils edge	22 V 39 V	-56 V	OK	OK
S7	2,600 V	More than 3 arcs				Small amount of neck shadow	OK
WJI	2,100 V	2 arcs	12.3 mils center 14 mils edge	35 V 48 V	-58 V	OK	OK
V1	2,650 V	No arcs	11.4 mils center 12.4 mils edge	30 V 45 V	-74 V	OK	OK

The seven groups of characteristics and the respective degrees of success achieved by the various rebuilders in meeting them are described below:

1. Focus: This includes center-screen focusing and center-to-edge focus variation. Focusing is the adjustment of the voltage on the G3 element to a level that produces the best resolution at a certain position on the CRT. The center-screen focus should fall within a specified range in order that the CRT's associated display electronics can focus the beam of the tube. With respect to the PVD, this range is between 2,600 and 3,000 volts. In CRT Specification E-2573, the change in focus voltage between the center and the edge is stated as being no more than 450 volts. Both of company M's and company D's CRT's had center-screen focusing outside the range of the specification; however, all of these CRT's were installed in displays and were focused.

2. Voltage Breakdown: Voltage breakdown is indicated by arcing inside the CRT which can severely damage circuitry in the display. The specification requires that no arcs occur when the tube is biased ON and the anode and focus elements are set at absolute maximum levels. Experience has shown that operationally acceptable CRT's sometimes arc a limited number of times for a short while after the tube is biased ON for the first time after having been stored or shipped.

If a CRT continues to arc regularly after the first 15 or 20 minutes of operation, it must be considered faulty. There were only three CRT's--all made by company S, that arced more than three times and continued arcing beyond the first 20 minutes of operation. In two of these samples, the arcing was so severe that we could not continue with the remaining electrical tests on them.

3. Resolution: At the fastest writing rate used for the CRT computer-driven data, and at 50 fL of brightness, no linewidth anywhere on the screen should exceed 20 mils. Since the spot-size on a CRT screen generally increases as it moves from the center to the edge, the linewidth should be no greater than 15 mils in the center. The rebuilders had the most difficulty with complying to the resolution specifications. This is an indication of the critical nature of the electron gun design. Even with the allowance of a 10-percent error in the measurement techniques, only 5 of the 17 rebuilt tubes tested for this property showed satisfactory resolution. Three of these CRT's were the single tubes rebuilt for operational use in a PVD by companies D, W/J, and V.

4. Modulation: The modulation characteristic is a function of the beam current versus the grid-drive voltage characteristic of the tube. The data from this test must fall within a certain range in order to attain the necessary brightness output in the host display. This range is determined by the characteristics of the video amplifier of the display. Three of the 14 CRT's measured had poor modulation characteristics, including the two produced by company M. Both of these CRT's, however, operated satisfactorily at the normal brightness levels used when installed in displays.

5. Cutoff Voltage: The cutoff voltage test determines the threshold of control grid voltage which completely inhibits the beam current. This measurement is taken when the CRT is biased with the normal voltages provided by the host display. Four CRT's were out of specification on this parameter.

6. Overall Display Legibility: This characteristic includes any brightness variations or "smearing" of data anywhere on the CRT screen. When using the scanning micrometer eyepiece on the photometer microscope, it is possible to have what appears to be satisfactory resolution at the half-maximum-brightness points, while observing a cross-section of a displayed line on a chart recorder, and still have what the eye sees as "smearing" of data. The operator can see the edges of the line probably down to 5 percent of the brightness intensity level of the line. This means that if the data are "smeared," the reader can see a much wider line than what the instrument reads.

Other problems included in the display legibility group would be neck shadow, and poor focusing in limited areas of the display screen. Because this is a large-bandwidth, wide-angle, random-writing display, the placement of the gun and yoke and the shape of the tube must be very precise in order to avoid neck shadow on the face of the tube.

Sometimes, there are problems in the construction of the focus electrode in the gun which can cause poor focusing in one or more small areas of the screen instead of the entire area. Two out of the five company W tubes and three out of the seven company S CRT's had neck shadow problems. Company W also produced two CRT's that displayed "smeared" data.

7. Mechanical Construction: This would include any obvious defects in the mounting of the implosion panel, fiberglass sleeve, gun connector, etc. Also included here would be a failure of the glass bulb during pressure testing, or a faceplate that was too flat. There were no major problems in these areas.

SUMMARY.

The CRT rebuilt by company V and one of the tubes rebuilt by company S were the two CRT's considered totally acceptable. This represented an 8-percent yield of acceptability out of a sample size of 25 CRT's. Seventeen out of these 25 CRT's were evaluated in the CRT Performance Test Set.

A separate table (table 3) is presented to compare the relative qualities of the tested CRT's from the various rebuilders to the specified limits. For each group of characteristics previously described, a grade of "1" or "0" was given for the particular CRT. A "1" indicated that the tube passed those particular tests inherent to its group. An index of merit was then calculated by evaluating the ratio of the total number of 1's for a CRT over seven, the total possible number. Fully acceptable tubes were those which earned a perfect score of 1. The closer the CRT "grade" approached a score of 1, indicated in the last column, the better the quality of the tube.

Two new nonrebuilt tubes produced by the original manufacturer (R1 and R2) are also included for comparison.

TABLE 3. RELATIVE RANKING OF REBUILT CRT'S

TUBE IDENTIFICATION	FOCUSING	VOLTAGE BREAKDOWN	AVERAGE RESOLUTION	MODULATION	CUTOFF VOLTAGE	OVERALL DISPLAY LEGIBILITY	MECHANICAL CONSTRUCTION	INDEX OF MERIT
R1*	1	1	1	1	1	1	1	1
R2*	1	1	1	1	1	1	1	1
V1	1	1	1	1	1	1	1	1
S6	1	1	1	1	1	1	1	1
D1	0	1	1	1	1	1	1	.86
W2	1	1	0	1	1	1	1	.86
WJ1	0	1	1	1	1	1	1	.86
W1	1	1	0	1	1	0	1	.71
W4	1	1	0	1	1	0	1	.71
S1	1	0	1	1	0	1	1	.71
S2	1	1	0	1	1	0	1	.71
S5	1	1	0	1	1	0	1	.71
S7	1	1	0	1	1	0	1	.71
M1	0	1	0	0	1	1	1	.57
M2	0	1	1	0	1	1	0	.57
W3	1	1	0	1	0	0	1	.57
W5	1	1	0	0	1	0	1	.57
S3	1	0	0	1	1	1	0	.57
S4	0	1	0	1	1	0	1	.57

*Not rebuilt. New production CRT's tested for comparative purposes.

CONCLUSIONS

It is concluded that:

1. The special electron gun is extremely difficult to duplicate and properly install.

2. The fiberglass boot removal can result in a serious safety problem and can increase the processing cost. Tubes with the fiberglass boot should not be rebuilt.

3. The used CRT screens have a higher rejection rate, since the blemishes, spots, or similar defects within the quality area are specified for higher resolution of information displayed than for television screens.

4. The special, relatively flat, large-surface-area faceplate of the 23-inch CRT requires special handling during the rebuilding and shipping processes to prevent possible damage from impact nicks and scratches.

5. The small sample size of usable tubes did not determine the feasibility of rebuilding FAA CRT's.

6. CRT rebuilders are not generally equipped to provide the test environment which special category manufacturers for government and industry must provide under their quality assurance program standards.

RECOMMENDATIONS

At the present time, there is no need for rebuilding the FAA 23-inch CRT's, since the bulb supplier has announced the availability and potential application of color television-type glass for these tubes. If, in the future, the supply of FAA CRT glass bulbs becomes uncertain, the following recommendations should be adopted:

1. Prior to initiating any testing or procurement of rebuilt CRT's:

   a. A cost/benefit analysis of processing, handling, shipping, and storage of the used CRT's should be conducted.

   b. An adequate sample size of the rebuilt CRT's for testing these tubes per FAA-E-2573 specifications should be determined.

   c. An investigation should be conducted to directly identify CRT rebuilding vendors who have facilities which are fully compatible with the application of FAA-E-2573 CRT specifications and FAA quality assurance program standards. Only these vendors should be considered acceptable for participation in an FAA CRT rebuilding program.

2. An adequate sample size of rebuilt CRT's, for a test program, should be procured from the approved rebuilding vendors and in equal quantities from each.

3. Further testing of rebuilt CRT's should be conducted to determine the feasibility of rebuilding FAA CRT's and to identify the rebuilding vendor(s) who have produced the greatest quantity of rebuilt tubes wholly satisfying the FAA-E-2573 specifications.

APPENDIX A

CATHODE RAY TUBE DATA

DATA SHEET

Tested By: NAFEC CRT Display Lab.

Tube Type: FAA 23-Inch

Serial No: #1 (V)

Date: 9/76

PARAMETER	E_{c1}	E_{c2}	E_{b1}	E_{b2}	I_k	E_f	I_f	E_{hk}	to E_{c1}		LIMITS		TEST		NOTES
UNITS	V d.c.	V d.c.	kV d.c.	kV d.c.	uA	V d.c.	mA	V d.c			Min.	Max.	RESULTS		
ELECTRICAL RATINGS															
Pin 2 Grid 1 E_{c1} (V)	Adj.										-170	0	Adj.		
Pin 10 Grid 2 E_{c2} (V)		600									500	850	600		
Al HV Anode E_{b1} (kV)			18								10	20	18		
Pin 6 Focus Anode E_{b2} (kV)				3.0							2.65	3.35	2.65		
Beam Current I_{b1} (μA)											0	300	0	300	
Pin 1, 12 Fil. Volts E_f (V)						6.3					5.67	6.93	6.3		
Fil. Current I_f (mA)							600				570	630	600	200	
Pin 11 Cathode E_{hk} (V)								-			-200	200	-200		
TEST CONDITIONS, LIMITS & RESULTS															
Focus Voltage - E_{b2} (KV)	Adj.	600	18	Adj.	60	6.3	-	-			2.65	3.35	2.65		Center screen focus
Cutoff Voltage - Spot (V)	Adj.	600	18	focus	-	6.3	-	-			- 85	-35	-74		
Cutoff Voltage Full Raster (V)	Adj.	600	18	focus	-	6.3	-	-			- 85	-35	-72		
Voltage Breakdown (arcs)	-170	850	20	3.35	-	6.3	-	-			0	2	0		Preheat 4 min. Apply V. After 30 sec. count arcs for 3 min.
Heater to Cathode Leakage I_{hk} (uA)	-170	600	18	3.0	-	6.3	-	+200			0	10	0		
Heater to Cathode Leakage I_{hk} (uA)	-170	600	18	3.0	-	6.3	-	-200			0	10	.1		
Grid 1 (G1) Leakage (uA)	-170	600	18	3.0	-	6.3	-	-			0	3	2		
Grid 2 (G2) Leakage (uA)	-170	600	18	3.0	-	6.3	-	-			0	5	0		
Anode Leakage (μA)	-170	600	18	3.0	-	6.3	-	-			0	5	5		
Stray Emission	-170	600	18	3.0	-	6.3	-	-				none	none		
Heater Current (mA)	-170	600	18	3.0	-	6.3	-	-			540	660	600		
Undeflected Spot Position (inches)	Adj.	600	18	focus	Note	6.3	-	-			0	.25	.25		I_k at a minimum to detect spot
Gas Ratio (μA)	Adj.	300	-24V	-25V	500	6.3	-	-			0	.06	.005		
Focus Anode Current (uA)	Adj.	600	18	focus	50	6.3	-	-			0	20	2		
Modulation (V)	Adj	600	18	focus	300	6.3	-	-			20	50	45		Measure
Modulation (V)	Adj.	600	18	focus	100	6.3	-	-			15	35	30		Measure
Screen Quality	(Good-Fair)														

Date: 9/76

Tube No. V1 23-INCH TUBE DATA COLLECTION

Writing Speed: .3 and .5 in./ sec

Additional Notes:

KEY Vertical Line Center-VLC
Horizontal Line Center-HLC
Vertical Line Right-VLR,
etc.

Brightness footlamberts	*Grid Drive volts	Focus Voltage volts	Line Width mils	Position on Tube (see Key)	Anode Voltage kilovolts
50	24	2575	11.3	VLC	18 kV .3 in./μsec
43	24	2900	10.3	VLT	18 kV .3 in./μsec
44	24	2875	10.1	VLB	18 kV .3 in./μsec
53	24	2800	14.2	VLL	18 kV .3 in./μsec
52	24	2800	13.5	VLR	18 kV .3 in./μsec
50	22	2650	11.5	HLC	18 kV .3 in./μsec
42	22	2850	14.2	HLB	18 kV .3 in./μsec
51	22	2825	14.4	HLT	18 kV .3 in./μsec
55	22	3000	10.1	HLL	18 kV .3 in./μsec
52	22	3025	11.5	HLR	18 kV .3 in./μsec

*Grid Drive is defined as the difference between the actual control grid voltage necessary to produce a given brightness and the cutoff voltage.

APPENDIX B

WORK STATEMENT FOR REBUILDING 23-INCH GLASS CATHODE RAY TUBES

1.0 Scope. This work statement specifies the requirements for rebuilding used, 23-inch glass Cathode Ray Tubes (CRT's) for use in FAA Air Traffic Control Displays.

2.0 Applicable Documents.

2.1 FAA Specifications. The following listed FAA specifications form a part of this specification to the extent referenced herein:

FAA-E-2573	Electron Tube, Cathode Ray 23-inch Glass--For use in Computer Display Channel Plan View Display Console.

3.0 Requirements.

3.1 General. The contractor shall rebuild and refurbish used 23-inch glass CRT's to meet the requirements specified herein.

3.1.1 Government-Furnished Equipment. The Government will provide used CRT's to the contractor for rebuilding. Each CRT will be provided complete with bonded faceplate and tension band. The CRT's will be shipped to the contractor in reusable tri-wall containers.

3.1.2. Incoming Inspection. The contractor shall inspect each CRT to determine that it is satisfactory for rebuilding. The contractor shall also inspect the phosphor on each CRT for inperfections, such as burn spots or patterns which could degrade performance of the rebuilt CRT.

3.1.2.1 Rejected CRT's. Any CRT which is rejected by the contractor for rebuilding shall be held for inspection by a Government representative and disposition instructions. The Government may direct the contractor to rebuild some CRT's which have minor phosphor burns or defects; in which case, a mutual agreement as to possible change in performance due to the phosphor defects will be negotiated.

3.1.2.2 Tri-Wall Containers. The contractor shall take normal precautions to prevent damage to the CRT reusable tri-wall containers, while these are at his plant. If a container is considered to be unsuitable for reuse, the Government representative shall be notified. The Government will provide replacement tri-wall containers, as required.

3.2 General Rebuilding Requirements. The contractor shall remove the laminated safety panel from the CRT, the tension (T) band and brackets, and the fiberglass cover on the bell. He shall remove and replace the electron gun in the CRT. The faceplate phosphor shall not be replaced. The exterior of the CRT glass shall be thoroughly cleaned and inspected for scratches, chips, cracks, etc. The conductive coating on the CRT exterior shall be redone to a like-new condition. The fiberglass cover shall be replaced, the laminated safety panel shall be rebonded to the CRT and the T band with brackets remounted. The CRT shall be evacuated and tested, as required.

3.2.1 FAA-E-2573 Requirements.

3.2.1.2 Paragraph 3.3.3.1, Conductive Coating. The conductive coating on the rebuilt CRT shall be repaired or reapplied so as to meet the requirements of this paragraph.

3.2.1.3 Paragraph 3.3.4, Tension Band. This paragraph shall apply, except that the T band and brackets shall be government-furnished property (GFP).

3.2.1.4 Paragraph 3.3.6, Lamination Plate and Epoxy Thickness. Applicable as written.

3.2.1.5 Paragraph 3.4, Marking. Change to read as follows:

> "Marking shall be permanent and legible, as described in method 1105 of MIL-STD-1311. It shall include the CRT rebuilder's company name, the original type No. and serial No., the words "Rebuilt Tube: and the date."

3.2.1.6 Paragraph 3.5.6, Allowable Surface Scratches; 3.5.7, Edge Chips; 3.6, Environmental Requirements; 3.6.1, Barometric Pressure; 3.6.2, Relative Humidity; and 3.6.3, Ambient Temperature--applicable as written.

3.2.1.7 Paragraph 3.7, Electrical/Photometric, through 3.7.21, Focus Anode Current--applicable as written.

3.2.1.8 Paragraph 3.8, Mechanical, Through 3.8.4, Side Terminal and Base alignment--applicable as written.

3.2.1.9 Paragraph 3.9, Safety Tests--applicable as written.

3.2.1.11 Paragraph 3.13, Deflection Yoke . This paragraph is changed as follows:

> The same type deflection yoke that is being used by the FAA in operational Plan View Displays shall be used by the contractor for performance tests. The Technical Officer will provide the contractor with the deflection yoke type number upon request.

4.0 Quality Assurance Provisions. The following requirements of FAA-E-2573 shall apply.

4.1 Paragraph 4.1, General, through 4.4., Inspection and Testing--applicable as written.

4.2 Paragraph 4.4.2.3. Secureness of Base, Cap, Insert and Permanence of Marking Tests; 4.4.31, Mechanical Tests; and 4.4.3.2, Electrical/Photometric Tests--applicable as written.

5.0 Packaging. Packaging shall be in accordance with the contract requirements.